THE PETROLOGY OF THE HARTLEY DISTRICT. IV.

THE ALTERED DOLERITE DYKES.

By Germaine A. Joplin, B.Sc., Ph.D., Department of Geology, University of Sydney.

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A study of the petrology of the Hartley District is incomplete unless mention be made of the numerous basic dykes that occur in the area.

In an introductory summary of the general geology of the area (Joplin, 1931), these dyke rocks were erroneously referred to as keratophyres. At that time only two specimens had been sectioned, and they contained albite and quartz. The writer was thus misled in considering them to be acid alkaline rocks. It is now known that the albite is deuteric, that the quartz grains are xenocrysts, and that the rocks have no affinities to the keratophyres.

Field Occurrence.

The dykes are very numerous and appear to form a swarm which invades members of the plutonic complex and the hornfelses of its contact aureole. They are rarely more than four feet in width and often considerably narrower, and the length of any single continuous mass is usually less than sixty feet, though side-stepping is frequent and several discontinuous outcrops may extend for longer distances.

The dykes follow prominent joint directions in the igneous or metamorphic rocks and they usually have plane parallel sides bounded by the joints in the country rocks. In such cases there is little doubt that the method of intrusion has been simple displacement or the widening of the joint fissure. There are a few dykes, however, notably one behind the Royal Hotel and a smaller one on Moyne Creek, which show transgressive relations and some evidence of stoping, and it is apparent that the igneous mass has come into its present position partly as the result of replacement of the country rock (Culey and Joplin, 1937).

The dykes that have been studied petrographically occur on Campbell's Creek and its eastern tributary, on the River Lett and its tributary behind the hotel, and on Moyne Creek. Others, however, are known to outcrop on Grant's Creek and south-west of Cox's River on the property of Mr. Chris. Commens. Frequently the dykes are much altered and appear as elongated masses of dark soil or as spheroidally weathered boulders.

Petrography.

In the hand-specimen the rocks are fine-grained and often somewhat stony. They vary from dull green to dark grey, the colour depending on the amount of chlorite present. Occasionally small pink phenocrysts of plagioclase are visible and specks of pyrites and calcite are not infrequent. Many of the dykes, especially

the one behind the hotel, contain xenocrysts of quartz and felspar (Culey and Joplin, 1937), which are usually about 2 mm. across, but may measure half an inch or more.

Under the microscope the rocks exhibit a variable grainsize, and consist of plagioclase phenocrysts in a groundmass of plagioclase, augite, iron-ore, brown hornblende and sometimes a little biotite, apatite and quartz. Chlorite, carbonates, sphene, haematite, prehnite and a zeolite may occur as deuteric minerals.

All the dykes have suffered deuteric alteration, and a single intrusion may show varying degrees of, and a patchy distribution of, the alteration.

The rocks are slightly porphyritic and the groundmass may be intersertal and/or subophitic or intergranular. In some cases the phenocrysts and larger felspars of the groundmass occur in a mass of chlorite and the rock has the appearance of a fine-grained porphyritic volcanic rock. This peculiar type, however, is associated with the normal rocks and appears to represent an advanced stage in the alteration of the groundmass.

Tabular phenocrysts of plagioclase measure 1 to 2 mm. and are often twinned according to the Carlsbad and Albite laws. In most cases the phenocrysts show incipient albitization along cleavage cracks (Bailey and Grabham, 1909), and the whole phenocryst is often entirely replaced. The original composition of the felspar appears to have been labradorite ($Ab_{49}An_{51}$). The phenocrysts not only show alteration to albite, but also to chlorite and/or calcite, and the chlorite may occur in selective zones in the felspar. The small plagioclase laths in the groundmass are andesine, varying in composition from $Ab_{68}An_{32}$ to $Ab_{57}An_{43}$, and are often altered to chlorite.

Augite occurs in stout prisms or rounded grains measuring up to 0·3 mm. These often mould the felspars, but may occur in small independent grains. The pyroxene is pale green in colour, $Z \wedge C = 40°$, and multiple twinning is often developed. 2V is small, but hardly small enough to justify the assumption that the pyroxene is approaching enstatite-augite. The mineral shows alteration to carbonates, chlorite or an amphibole, the two first being the more common. In many of the altered rocks no pyroxene is present at all, but its original presence is suggested by masses of carbonates and chlorite.

Brown hornblende is present only in the less altered types and occurs only in small amount. It forms slender idiomorphic prisms measuring 0·3 mm. X = pale yellow, Y = pale brown, Z = dark brown ($Z > Y > X$); $Z \wedge C = 17°$. It is optically negative and the elongation is positive.

Biotite is occasionally present in small brown flakes, and contains lenses of prehnite (Joplin, 1936). Iron-ores are abundant in small rounded grains or octahedra and their form suggests magnetite, but the percentage of titania in the analysed rock indicates that it is probably a titaniferous magnetite; moreover, sphene is a common alteration product.

Chlorite varies in amount. In the less altered types it may be seen filling cracks and fringing pyroxenes and often replacing certain zones in the plagioclase phenocrysts. In the more altered types the rock may be almost completely chloritized and appears distinctly green in the hand-specimen. More than one variety of chlorite is present, but the rocks are very fine-grained so that the chlorites cannot be separated and their refractive indices determined. A variety commonly associated with augite, however, has a yellowish-green colour, is optically negative, the elongation is positive, and the interference colours are low first order. It thus appears to be a variety containing very little alumina and a large proportion of iron and magnesia. Masses of chlorite, showing the characteristic ultra-

blue of pennine, seem to have developed from the felspars of the groundmass. The rocks often contain solution-cavities filled with this mineral in association with carbonates and sometimes with a zeolite.

Apatite is very sporadic in its development. In some rocks it is entirely absent, and in others is quite abundant and occurs as slender prisms or needles included in the minerals of the groundmass.

Quartz occurs either as xenocrysts which show corrosion, or as a released mineral among the alteration products. It seems unlikely that any of the quartz is of primary consolidation.

Some of the rocks are more albitized than others; in some there is a greater abundance of carbonates or of chlorite, and it is evident that widely different results would be obtained if these extreme types were analysed. All types, however, show characteristic deuteric alteration, and in the rock chosen for analysis (column I below) no one of these processes has gained ascendancy over another.

Although the alteration of the Hartley rock is deuteric and characteristic, it is too altered for the norm to serve any useful purpose.

	I.	II.	III.	IV.	V.
SiO_2	46·84	46·02	48·07	50·60	49·50
Al_2O_3	18·59	18·03	19·02	17·40	14·37
Fe_2O_3	5·75	7·17	7·65	4·57	6·55
FeO	4·86	2·78	4·83	6·29	5·84
MgO	3·89	4·83	3·30	4·89	7·75
CaO	9·06	8·68	9·84	8·09	9·96
Na_2O	2·21	3·31	2·84	3·23	2·50
K_2O	0·80	1·33	0·63	1·76	0·84
H_2O+	2·45	3·22	1·69	1·83	0·66
H_2O-	0·87		0·43		
TiO_2	1·35	0·95	1·72	0·68	1·42
P_2O_5	abs.	0·35	abs.	0·20	0·44
MnO	0·10	—	0·21	0·46	0·17
CO_2	2·81	2·90	abs.	—	—
Other Const.	—	—	0·33	—	—
	99·58	99·57	100·56	100·00	100·00

I. Altered Dolerite. Dyke on River Lett, between Lett and Glenroy Bridges. Anal. G. A. Joplin.
II. Melaphyre. Sommerberg, Thuringerwald. Anal. G. F. Steffen. In W.T., p. 876, No. 110.
III. Altered Diabase. Tamarack, Minnesota. Anal. A. W. Johnston. In W.T., p. 868, No. 36.
IV. Osann's average melaphyre (Daly, 1914, p. 27).
V. Osann's average dolerite (Daly, 1914, p. 27).

Name of the Rock.

It is evident from the foregoing petrography and from the chemical analysis that the rocks have suffered much deuteric alteration, and this must be taken into consideration in naming the rock.

The chemical and mineral composition and the mode of occurrence suggest some type of dolerite.

As quartz occurs either as xenocrysts or as a released mineral, its presence cannot be taken into account; moreover, there is nothing else to suggest that the rocks may have been quartz-dolerites.

Many of the less altered types, however, contain small quantities of brown hornblende, and the dolerites may thus be called hornblende-dolerites or proterobases. The proterobase is regarded as a member of the spilite suite (Dewey and Flett, 1911) and, like all members of this suite, they are characteristically albitized and chloritized. These alteration products are quite common among normal basic rocks, and even if there be a spilite suite, there seems no reason why the Hartley dykes should not be regarded simply as deuterically altered dolerites, which sometimes contain a little primary hornblende.

Similar Dykes elsewhere in New South Wales.

In the three granite areas examined by the writer, namely, Hartley, Sodwalls and Gumble, altered dolerite dykes have been found associated with granite.

At Sodwalls one such dyke cuts the granite near Wilson's Quarry on the Old Railway Line just north-east of Sodwalls station. In the hand specimen and under the microscope this rock is identical with one from Hartley. Other similar dykes occur in the Sodwalls granite, but they have not been observed among the sedimentary rocks outside the contact aureole.

At Gumble only one basic dyke is recorded. This may be observed cutting acid dykes about 800 yards from the granite contact in Portion 21, Parish of Gumble. Petrographically this rock also compares closely with Hartley and Sodwalls types.

L. A. Cotton (1915) has described two large dolerite dykes at Copeton in the New England. These were investigated for an economic reason, as two diamonds in a doleritic matrix had been found in the area. The present writer has had the privilege of examining Professor Cotton's slides, and has found that the Copeton and Hartley rocks compare very closely. The Copeton dolerites contain a little quartz and, though some of it appears to have been derived from the granite, as at Hartley, a part of it may be primary and the rocks may have affinities with the quartz-dolerites. At Copeton the dykes invade the acid granites of the New England Complex and are partly overlain by Tertiary basalts with which they have no petrological connection.

Geological Age of the Dykes.

The geological age of the Hartley dykes is uncertain. They are post-granite and pre-Kamilaroi, but that is all that can be deduced from the field evidence, although the fact that they are never found outside the contact aureole may have some significance. At Hartley, however, the Kamilaroi overlies the Upper Devonian Series on the north and east, and it is impossible to examine the older formation at any great distance from the contact-zone. Nevertheless, similar dykes at Sodwalls, at Gumble, and at Copeton, appear to be restricted to an area close to the granite.

This slender evidence suggests that the dyke swarm belongs to the plutonic complex and it is pertinent to examine the chemical evidence.

It has been pointed out that the analysed rock is characteristically altered and that, with its rather low magnesia, it compares with other altered doleritic rocks. Magnesia, therefore, appears to be lost during the process of alteration, and local concentrations of chloritized dolerite (see p. 265) suggest that MgO is subtracted from one part of the dyke and accumulated in another.

The Hartley dykes show three types of alteration—albitization, chloritization and alteration to carbonates, and the rock chosen for analysis was one in which all three types were present in about equal amount. To some extent, therefore, the low magnesia must be regarded as an inherent property of the magma.

In column II below, the dolerite has been re-calculated to 100% omitting carbon dioxide and water, both of which play an important part in the deuteric processes. Column III represents the composition of a hypothetical rock interpolated from the variation-diagram of the Hartley plutonic series (Joplin, 1931, 1933). The high Al_2O_3 and MgO < FeO is noteworthy in the two analyses, and their close correspondence is suggestive, but not entirely convincing. Nevertheless, in the absence of other evidence as to the age of the basaltic dykes, it seems reasonable to consider them as a late phase of the plutonic intrusion, which would correspond to the normal lamprophyric end-phase.

	I.	II.		III.	
SiO_2	46·84	50·12		50·10	
Al_2O_3	18·59	19·89		19·90	
Fe_2O_3	5·75	6·15	11·75	5·20	11·53
FeO	4·86	5·22		5·70	
MgO	3·89	4·16		4·40	
CaO	9·06	9·69		9·80	
Na_2O	2·21	2·36		2·15	
K_2O	0·80	0·86		0·80	
H_2O+	2·45	—		—	
H_2O-	0·87	—		—	
TiO_2	1·35	1·45		0·80	
P_2O_5	abs.	abs.		0·35	
MnO	0·10	0·10		0·15	
CO_2	2·81	—		—	
	99·58	100·00		99·35	

I. Altered Dolerite. Dyke on River Lett between Lett and Glenroy Bridges, Hartley. Anal. G. A. Joplin.
II. Column I re-calculated to 100% omitting carbon dioxide and water.
III. Hypothetical rock interpolated from variation-diagram of the Hartley plutonic series (Joplin, 1931).

The Possibility of a Basaltic End-phase.

The grain-size of the dolerites and their method of emplacement indicate that the granite was solid before the invasion of the dykes. The assimilation of some of the granitic material (Culey and Joplin, 1937), however, suggests that the plutonic rock may have been still hot when it was engulfed by the basic magma.

Bowen (1915, 1928) has pointed out that the sinking and resorption of biotite and hornblende crystals during the granite stage of differentiation of a basaltic magma will cause an enrichment of alkalis in the melt. The resorption of hornblende crystals in the "hot liquid" will give rise to a series of more basic minerals such as olivine, augite and anorthite, and these will be precipitated, since they are not in equilibrium with the liquid phase. In this way it is possible to account for the late formation of basic lamprophyres in plutonic complexes.

It seems not unreasonable to suppose that a doleritic rock may be derived from these basic constituents, and instead of the parallel development of an independent alkaline rock, it is possible that the concentrated alkalis and volatiles will react with the dolerite, causing albitization and other deuteric phenomena.

Furthermore, Bowen (1928, p. 270) explains that the "hot liquid" necessary for the resorption of hornblende must be of the nature of a basaltic liquid, and if such be available at this late stage in the differentiation process, it is not unlikely that it could be injected without differentiation as basalt or dolerite dykes.

Summary and Conclusion.

A series of altered dolerite or proterobase dykes are described. These invade granite and the metamorphic rocks of its contact aureole, and it is suggested that the dykes may be an end-phase of the plutonic intrusion. Chemical evidence is adduced to support this suggestion, and the possible type of differentiation is briefly discussed.

In conclusion, it is suggested that basaltic dyke-rocks may take the place of, or occur with, lamprophyres as an end-phase in a plutonic series. In view of the fact that altered dolerite dykes have been found associated with granites in the only three granitic masses examined by the writer, it seems possible that careful search may reveal them in other areas. Granites and associated dyke-rocks are described from numerous mining regions, but in many cases the reports do not concern themselves with petrological detail and most of the basic dykes are said to be lamprophyres. It seems not unlikely that, if more detailed petrographic work be carried out, some of the "lamprophyre" dykes may prove to be of a basaltic nature.

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